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# AN INVESTIGATION OF THE STRENGTH OF ROLLED ZINC

BY

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UNIVERSITY OF ILLINOIS
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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

BULLETIN NO. 52 DECEMBER 1911

# AN INVESTIGATION OF THE STRENGTH OF ROLLED ZINC

BY HERBERT F. MOORE, ASSISTANT PROFESSOR IN THEORETICAL AND APPLIED MECHANICS

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# AN INVESTIGATION OF THE STRENGTH OF ROLLED ZINC.

## I. Introduction.

1. *Uses of Zinc.*—Zinc is used as a constituent of brass and other alloys, as a protective coating for iron and steel plate and pipe, and as a preventive against rusting out of steam boiler tubes. It is used for making fruit jar covers and corrosion-resisting cans and boxes. In the form of wire, it is used for making shoe nails, and in the form of plates, it is used for making etchings (line cuts) for the reproduction of drawings. Zinc has a wide use as the electro-negative element in electric batteries. The ductility of zinc is an important factor in the manufacture of fruit jar covers, cans, battery zincs, or in other cases when it is to be bent or stamped into shape. Zinc is rarely used as a stress-carrying member of a machine or structure; in Europe thin zinc plates are sometimes used for roofing, and in a few cases electric cables have been suspended by strips of sheet zinc, which resist atmospheric corrosion better than do strips of steel plate.

2. *Purpose of Investigation and Acknowledgment.*—The occasional use of sheet zinc hangers for supporting electric cables called the attention of the Matthiessen and Hegeler Zinc Company of La Salle, Illinois, to the question of the strength of rolled sheet zinc, and it was found that few data were available. The matter was referred to the attention of the Engineering Experiment Station of the University of Illinois, and the general subject of the strength of rolled zinc seemed to be of sufficient importance to warrant making tests. A series of tests of strength of zinc was made in the Laboratory of Applied Mechanics of the University of Illinois, by the writer, under the general direction of Professor Arthur N. Talbot, head of the Department of Theoretical and Applied Mechanics.

In addition to tension tests of zinc, tests of rolled zinc under punching and shearing were made. In the course of the investigation, several tests of cast zinc were made, including torsion and compression tests, and also cold bending tests of rolled zinc. The results of all these tests are recorded in this bulletin.

3. *Existing Data on the Strength of Rolled Zinc.*—The principal tests on the strength of rolled zinc have been made by Bauschinger, Martens, and Meyer. Bauschinger's tests* showed the effect of rapidity of loading on the properties of zinc. The influence of duration of test on the strength of cast zinc was slight, but with rolled zinc, rapidity of testing increased the tensile strength. In tests lasting 6 min., the average ultimate tensile strength was 29 100 lb. per sq. in.; in tests lasting 81 min., the average ultimate tensile strength was 23 300 lb. per sq. in.

TABLE 1.

TENSION TESTS OF ROLLED ZINC; EFFECT OF THICKNESS AND OF DIRECTION OF ROLLING (MARTENS).

| Thickness of Plate—inches | Ultimate Tensile Strength lb. per sq. in. | |
|---|---|---|
| | With Grain (Parallel to Direction of Rolling) | Across Grain (Perpendicular to Direction of Rolling) |
| 0.019—0.222 | 26 600—14 200 | 31 800—20 200 |

TABLE 2.

TENSION TESTS OF ROLLED ZINC; EFFECT OF TEMPERATURE OF TEST SPECIMEN (MARTENS).

| Temperature of Specimen Degrees Fahr. | Ultimate Tensile Strength lb. per sq. in. | Elongation after Rupture per cent |
|---|---|---|
| 66—81 | 20 600 | 12.4 |
| 176 | 12 500 | 29.4 |
| 248 | 8 960 | 59.4 |
| 302 | 5 790 | 101.5 |
| 338 | 7 960 | 17.1 |
| 392 | 6 120 | 7.2 |

Martens'† investigations of the strength of zinc dealt with the influence on strength of thickness of plate, of direction of rolling, and of temperature. His results are summarized in Table 1 and Table 2. From these results, it would seem that about 300° F. is the most favorable rolling temperature for zinc plates, as at that temperature the strength is low and the ductility a maximum. All Martens' tests were made on zinc refined from Silesian ores.

*Mitteilungen aus dem mechanisches—technische Lab. der Technische Hochschule im Munchen, 1887, Heft 20, Seite 16.

†Mitteilungen aus mech—tech. Versuchstantalten in Berlin, Erganzungsheft IV.

An extensive series of tests of the strength of zinc plates was made by Dr. Oswald Meyer of Vienna*. The plates tested by him were all rolled at the zinc works of Cilli, in Austria. The plates contained from 0.021 to 1 04 per cent of lead, 0.03 to 0 912 per cent of cadmium, 0.02 to 0.03 per cent of iron, from a trace to 0.009 per cent of copper, and a trace of arsenic. Tests were made of (a) plates as received from the zinc works; (b) plates treated with nitric acid; and (c) plates subjected to heat treatment before testing. The results of Meyer's tension tests of plates as received from the zinc works, are shown in Table 3.

TABLE 3.

TENSION TESTS OF ROLLED ZINC (MEYER).

Tests of zinc as received from the rolling mill.
Thickness of plate tested varied from 0.044 in. to 0 051 in.

| Item | With Grain | Across Grain | Average |
|---|---|---|---|
| Stress at first permanent set, lb. per sq. in. | 1 990 | 2 420 | 2 130 |
| Stress at limit of proportionality of stress to deformation, lb. per sq. in. | 710 | 1 280 | 995 |
| Yield point, lb. per sq. in. | 11 400 | 13 640 | 12 500 |
| Ultimate, lb. per sq. in. | 30 400 | 36 800 | 33 600 |
| Elongation, per cent | 27.2 | 9.7 | 18.5 |
| Reduction of area, per cent | 43 | 17 | 30 |
| Modulus of elasticity, lb. per sq. in. | 12 850 000 | 14 500 000 | 13 620 000 |

The following features of Meyer's tests are worthy of note: Specimens cut across grain (perpendicular to the direction of rolling) are somewhat stronger and stiffer than specimens cut with the grain (parallel to the direction of rolling).

The ductility of specimens cut with the grain is greater than that of specimens cut across the grain. Stresses at elastic limit and yield point are very low, the yield point is not sharply marked, and the flow of metal under high stress goes on for a long time.

The tests of zinc plates treated with acid show that a 10 min. immersion in 5 per cent nitric acid did not appreciably lessen the strength or the ductility of the zinc plate.

A series of tests was made by Dr. Meyer on zinc plates subjected to the following heat treatment before testing in tension:

*Oesterreichische Zeitschrift fur Berg und Huttenwesen, Oct. 7 and 14, 1905.

The specimens were subjected for one hour to a temperature of 527° F., when upon testing they developed the properties indicated in Table 4 (average values).

The ultimate strength in tension and the ductility are decidedly lowered by this heat treatment. The "critical temperature" for zinc was found to be at about 300° F. and the heat transformation of the zinc took place very rapidly, one minute being seemingly sufficient to effect it. The tests of Martens and of Meyer point to the desirability of keeping the working temperature during the rolling of zinc within narrow limits. Meyer recommends 302° F. as a maximum rolling temperature.

Meyer also made tests to show the effect of alloying zinc with cadmium and with lead. He found that the addition of 0.2 per cent of cadmium improved the quality of zinc plate, but that the addition of 0.4 per cent of either cadmium or lead either produced no appreciable effect or injured the quality. The addition of both cadmium and lead lowered both the strength and the ductility of zinc plate.

The Matthiessen and Hegeler Zinc Company of La Salle, Illinois, report a series of tension tests of zinc plate made at their request in 1907. The thickness of the plate tested varied from 0.011 in. to 0.04 in., the average tensile strength for sixty specimens was 29 370 lb. per sq. in. The thinner plate showed slightly greater strength than the thicker plate.

## II. Specimens, Tests, and Methods of Testing.

4. *Source of Supply of Zinc for Tests.*—The zinc tested at the University of Illinois came from the zinc works of the Matthiesson and Hegeler Zinc Company at La Salle, Illinois, and from the stock of a local hardware store. The zinc from the Matthiessen and Hegeler Company was smelted from ores from the Joplin, Missouri, district. Several specimens of cast zinc were furnished which were remelted spelter poured directly into moulds. Eighteen sheets of rolled zinc, each 18 in. by 20 in., were furnished, varying in thickness from 0.006 in. to 1.0 in. Three sheets of each thickness were furnished, and each of the three sheets was from a different heat. No special precautions as to heat treatment were taken either with the cast zinc or with the rolled zinc. As a check on the values obtained for the zinc plates furnished by the Matthiessen and Hegeler Zinc Co., tests were made on sheet zinc purchased in the local market (Champaign, Illinois).

TABLE 4.

TENSION TESTS OF HEAT TREATED ZINC (MEYER).

| | |
|---|---|
| Stress at first permanent set.. | 2 480 lb. per sq. in. |
| Stress at limit of proportionality of stress to deformation ........................ | 1 710 lb. per sq. in. |
| Yield point.................... | 11 100 lb. per sq. in. |
| Ultimate........................ | 17 500 lb. per sq. in. |
| Elongation ..................... | 4.6 per cent |
| Reduction of area ............ | 5 per cent |
| Modulus of elasticity............ | 15 950 000 lb. per sq. in. |

5. *Test Specimens.*—Specimens of cast zinc were tested in tension in compression, and in torsion. Specimens of rolled zinc were tested in tension, in cold bending and in shear; the tests in shear included punching tests and tests in direct shearing. The specimens for tension tests of cast zinc were similar in form and dimension to the specimen shown in Fig. 1. The cast zinc was furnished in bars 1¼ in. square by 12 in. long and machined to the size shown in Fig. 1.

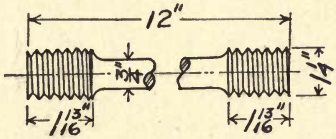

FIG. 1. TENSION SPECIMEN FOR CAST ZINC.

Fig. 2 shows the form and dimension for the specimens of cast zinc tested in torsion. The specimens of cast zinc tested in compression were circular cylinders 1 in. in diameter by 1½ in. long. They were machined all over.

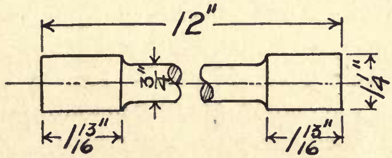

FIG. 2. TORSION SPECIMEN FOR CAST ZINC.

Fig. 3 shows the size of the plates of rolled sheet zinc furnished by the Matthiessen and Hegeler Company, and also shows the plan followed in cutting test specimens from the plates. The specimens similarly located in different plates were stamped with the same number, the plate being designated by a letter. The specimens for tension tests of rolled zinc were similar in form and dimension to the specimen shown in Fig. 4. The strips from which they were machined out were sheared from an 18 in. by 20

in. plate in all cases except some of the plates 1.0 in. thick, in which it was found impossible to shear strips from the plate without seriously injuring it. In these thick plates, the strips from which the tension specimens were machined were cut from the plates by drilling. The tension specimens of rolled zinc were machined on a shaper to the shape shown in Fig. 4.

The punching and shearing tests for rolled zinc were made on the portion of the 18 in. by 20 in. plates remaining after the tension test pieces had been cut out. The holes punched in the punching tests were separated by a distance at least 1½ times the diameter of the punch used. The shearing tests were made on specimens cut from the portion of the plates left after the punching tests had been made. The shearing test specimens were cut 1 in. wide, and were sheared in double shear. Some specimens were sheared across the grain (perpendicular to the direction of rolling) and some with the grain (parallel to the direction of rolling).

Cold bending tests were made on small strips of zinc about 1 in. wide cut from any portion of the 18 in. by 20 in. plates remaining after the other tests had been made. For each plate tested in cold bending, one specimen was bent in a plane parallel to the direction of rolling (with the grain), and one specimen was bent in a plane perpendicular to the direction of rolling (across the grain).

The sheet of zinc bought in the local market differed in size from those furnished by the Matthiessen and Hegeler Company, but the general method of cutting specimens from it was the same as that just described.

6. *Testing Machines and Auxiliary Apparatus.*—Some of the tension tests of zinc were made on a Riehle 100 000–lb. testing machine, others on an Olsen 10 000-lb. testing machine, and still others on a Riehle 100 000–lb. testing machine fitted with an Olsen 1000–lb. spring balance for measuring load. The tension specimens for cast zinc were held in threaded-ended sockets; the tension specimens for rolled zinc were held by means of flat wedge grips. For measuring the elongation in the tension tests, the extensometer used in the routine testing of the Laboratory of Applied Mechanics for several years was used. The indicating pointer of this extensometer is operated by a drum round which is wrapped a fine insulated copper wire which by friction causes the rotation of the drum and the pointer over a dial as the specimen stretches. The extensometer read to $\frac{1}{10\,000}$ in. elongation.

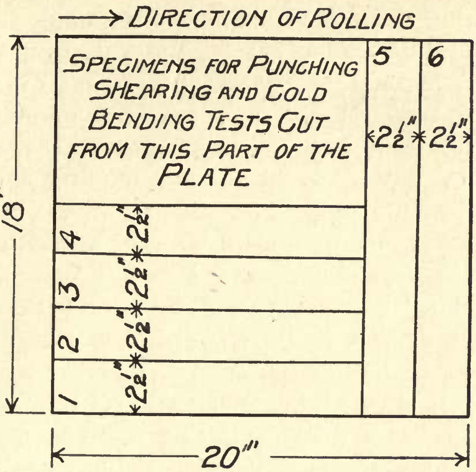


FIG. 3. ZINC PLATE SHOWING LOCATION OF SPECIMENS.

The torsion specimens of cast zinc were tested in a Riehle 10 000–lb. in. torsion testing machine of the pendulum type. The machine was hand operated during the tests, and the specimens held by self-centering and self-tightening toothed jaws. The angle of twist was measured by means of two dials and pointers similar to the dial and pointer on the extensometer used in the tension tests. The reading of each dial showed the twist of a section of the specimen with reference to the framework of the testing machine; the difference of the dial readings at the two sections gave the angle of twist of the specimen between the two sections at which the dials were attached.

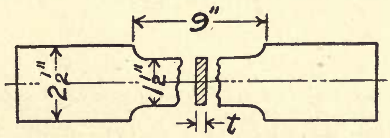


FIG. 4. TENSION SPECIMEN FOR ROLLED ZINC.

The compression specimens of cast zinc were tested in a 100 000-lb. Riehle testing machine. The ends of the specimens were carefully machined to a plane surface, and pressure was transmitted to the specimen through a spherical seated block. Compression was measured by means of a Ewing microscope compressometer reading to $\frac{1}{125\,000}$ in.

The punching tests of rolled zinc were made with hardened steel punches and dies mounted on the weighing table of a testing machine. The punches used were 0.505 in., 0.747 in., and 1.001 in. in diameter, respectively, and the corresponding dies were 0.61 in., 0.86 in., and 1.13 in. in diameter, respectively. The punches were flat faced. Most of the punching tests were made with a speed of punch so slow (0.1 in. per min.) that the weighing beam of the testing machine could be kept in balance by hand as the test progressed. Nearly all the punching tests were made on a Riehle 100 000-lb. testing machine fitted with an autographic apparatus which drew a diagram showing motion of punch as abscissas and load applied as ordinates. It was desired to run some punching tests at a higher speed than 0.1 in. per min., but as it was impossible to keep the weighing beam accurately balanced by hand in these tests, a steam engine indicator was attached to the testing machine weighing beam, so that the compression of the indicator spring measured the load on the punching tool*. Punching tests of very thin plates of zinc were made on an Olsen 10 000-lb. testing machine, and only the maximum load was recorded.

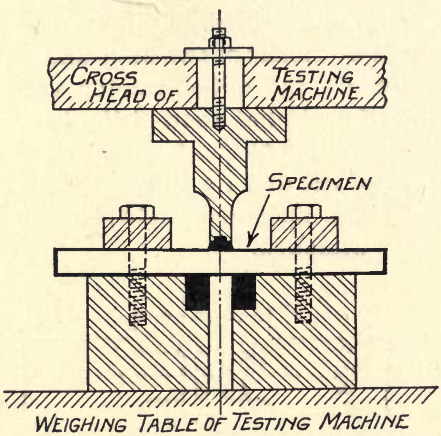


FIG. 5. APPARATUS FOR SHEARING TESTS.

Shearing tests of rolled zinc were made in a 100 000-lb. Riehle testing machine fitted with autographic recording apparatus. A hardened steel shearing tool cut the specimen in double shear. Fig. 5 shows the arrangement of the shearing tool. Most of the shearing tests were run at a low speed of tool (0.1 in. per min.) and the weighing beam of the testing machine was kept balanced

*For description of this apparatus see the Proceedings of the American Society for Testing Materials for 1908, p. 653.

by hand, while an autographic record was taken of the load and the motion of the shearing tool. Some shearing tests were made at a higher speed, and for these the steam engine indicator device for weighing loads was used as in the punching tests at high speeds.

7. *Data of Tension Tests.*—Table 5 gives the log of a sample tension test of zinc. The same general method was followed for all tension tests; both deformation under load and set after release of load were observed. During several of the tests, especially in the tests of cast zinc, a cracking noise was plainly audible under stresses as low as two-thirds of the ultimate. A set was detected in most tests after the removal of the first load applied, however low. After rupture the elongation over a gauge length originally measuring 8 in. and the reduction of area at the point of fracture were both measured when the rupture was inside the gauge length.

TABLE 5.

LOG OF SAMPLE TENSION TEST OF ROLLED ZINC.

Specimen H. 3. Dimension of Cross-section, 1.486 in. x 0.612 in.
Elongation after rupture 9.5% in 8 in.
Reduced cross-section 1.439 in. x 0.544 in.
Specimen tested with the grain.

| Load lb. | Extensometer in. | Load lb. | Extensometer in. |
|---|---|---|---|
| 1 000 | 0 | 8 000 | 0.0091 |
| 3 000 | 0.0015 | 1 000 | 0.0054 |
| 1 000 | 0.0006 | 8 750 | 0.0120 |
| 5 000 | 0.0031 | 1 000 | 0.0076 |
| 1 000 | 0.0011 | 9 500 | 0.0155 |
| 7 000 | 0.0066 | 1 000 | 0.0104 |
| 1 000 | 0.0035 | 19 530 | rupture |

In the tests of cast zinc and of the thinner specimens of rolled zinc the failure was, in general, sudden. In the very thin specimens of sheet zinc the failure occurred by tearing across, and in a few cases its course could be followed by the eye. Fig. 6 and 7 show typical stress-elongation diagrams of tension tests. Table 6 shows the summarized results of tension tests of zinc. There was considerable variation in strength shown by individual specimens of cast zinc, the ultimate strength ranging from 6 050 lb. per sq. in. to 12 220 lb. per sq. in. There was little variation in strength shown by individual specimens of rolled zinc. The extreme values were, in general, within 10 per cent of the mean. No

## TABLE 6.

### Tension Tests of Zinc.

The values given are the average results for the number of specimens noted in the second column.

| Thickness of Rolled Plate in. | Number of Specimens | Stress at First Noticeable Set lb. per sq. in. | Stress at Limit of Proportionality lb. per sq. in. | Stress at Ultimate lb. per sq. in. | Modulus of Elasticity lb. per sq. in. | Elongation in 8 in. per cent | Reduction of Area per cent | Speed of Pulling in. per min. | Specimens Tested with or across Grain |
|---|---|---|---|---|---|---|---|---|---|
| Cast | 6 | 1600 | 2100 | 9 060 | 11 025 000 | slight | slight | hand | —— |
| 1 | 5 | 0+* | 0+ | 22 200 | —— | 7.56 | 8.72 | 0.3 | With grain |
| 1 | 4 | 900 | 2900 | 21 340 | 10 450 000 | 4.85 | 6.58 | 0.5 | With grain |
| 1 | 3 | 900 | 4600 | 23 050 | 10 370 000 | 0.31 | 5.37 | 0.5 | Across grain |
| 0.6 | 12 | 0+ | 4200 | 21 490 | 11 033 000 | 16.63 | 22.25 | 0.5 | With grain |
| 0.6 | 5 | 0+ | 4000 | 23 550 | 10 780 000 | 3.33 | 5.80 | 0.5 | Across grain |
| 0.25 | 12 | 0+ | 5150 | 23 770 | 12 767 000 | 11.90 | 19.17 | 0.5 | With grain |
| 0.25 | 6 | 0+ | 5000 | 22 260 | 10 967 000 | 0.27 | 5.07 | 0.5 | Across grain |
| 0.10 | 6 | 0+ | 3600 | 22 280 | 10 650 000 | 18.75 | —— | 0.5 | With grain |
| 0.10 | 6 | —— | —— | 24 870 | —— | 21 00 | —— | 3.25 | With grain |
| 0.10 | 6 | 0+ | 5500 | 33 620 | 13 700 000 | 14.3 | —— | 0.5 | Across grain |
| 0.018 | 6 | 0+ | 5800 | 25 490 | 10 533 000 | —— | —— | 0.5 | With grain |
| 0.018 | 8 | —— | —— | 29 810 | —— | —— | —— | 1.37 | Across grain |
| 0.018 | 3 | —— | —— | 23 840 | —— | —— | —— | 0.2 | With grain |
| 0.018 | 6 | —— | —— | 34 960 | —— | —— | —— | 0.5 | Across grain |
| 0.006 | 6 | —— | —— | 24 110 | —— | —— | —— | 0.2 | With grain |
| 0.006 | 6 | 0+ | 5100 | 26 480 | 14 800 000 | 6.5 | —— | 0.5 | With grain |
| 0.006 | 3 | —— | —— | 33 830 | —— | —— | —— | 0.5 | Across grain |
| 0.006 | 3 | —— | —— | 38 440 | —— | —— | —— | 2.5 | Across grain |
| 0.018† | 3 | —— | —— | 24 200 | —— | —— | —— | 0.5 | With grain |
| 0.018† | 2 | —— | —— | 35 150 | —— | —— | —— | 0.5 | Across grain |

*When the stress is given as 0+, a value below the lowest reading taken is denoted.

†Specimens from zinc bought in the local market; all specimens not specially designated were cut from zinc furnished by the Matthiessen and Hegeler Zinc Company.

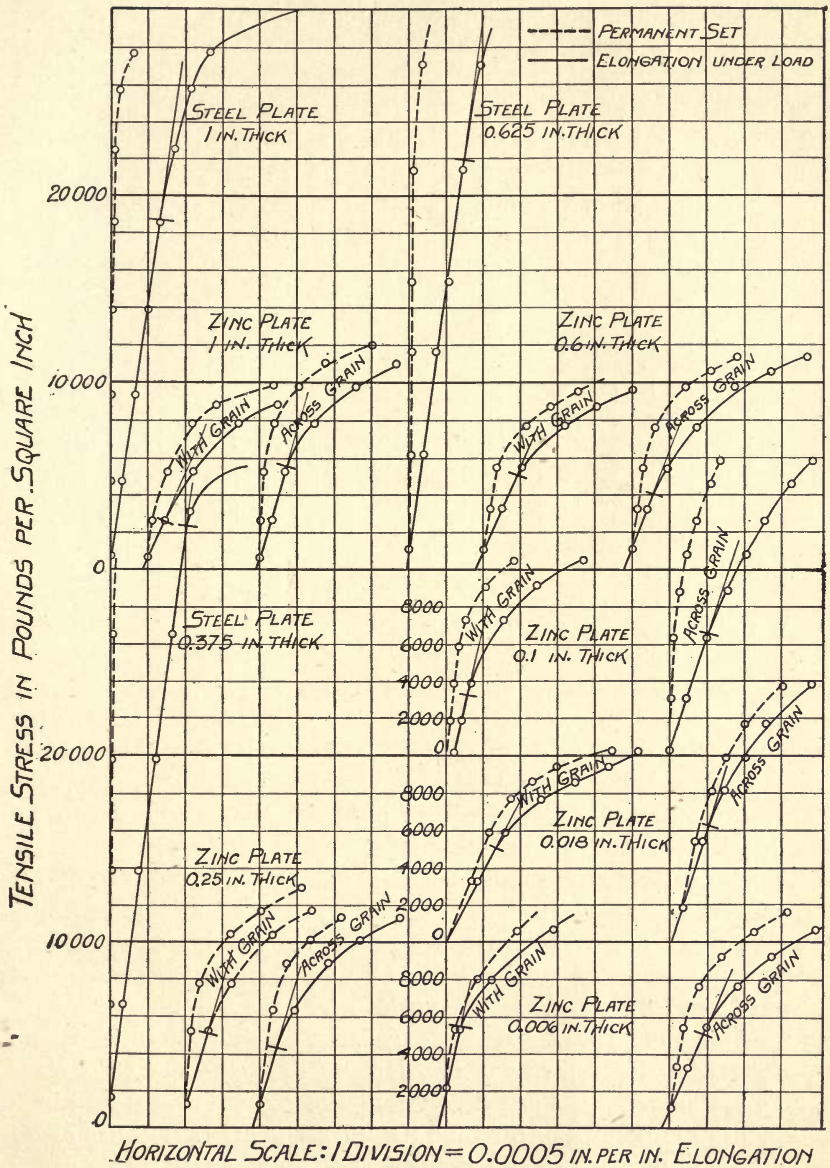


FIG. 6. TENSION TEST DIAGRAMS FOR ROLLED ZINC.

well-defined yield point could be determined in any tension test.

Fig. 8 shows two characteristic fractures of cast zinc in tension. The specimen at the left of the cut shows a much coarser grain than the one on the right; it also showed much lower tensile strength. Fig. 9 shows characteristic fractures of rolled zinc in tension. The specimen at the left is from a very thin plate, and it failed by tearing across. The specimen in the center is from a plate 0.25 in. thick, and it failed with very little elongation. The specimen at the right is from a plate 0.6 in. thick, and it showed great elongation. The necking down of the ductile specimen can be seen in Fig. 9.

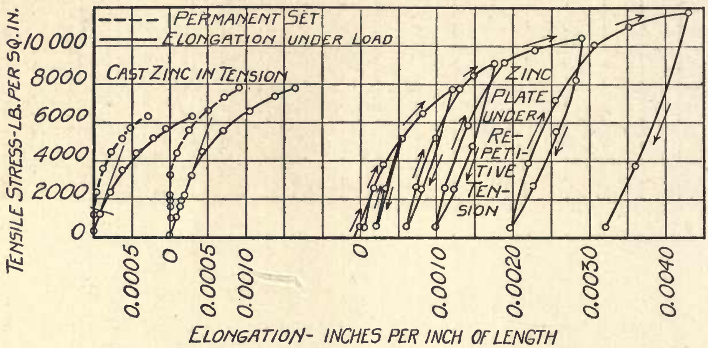


FIG. 7. TENSION TEST DIAGRAMS FOR ZINC.

8. *Data of Punching and Shearing Tests*—The data for the punching and the shearing tests were all autographic except for punching tests in very thin plates. Fig. 10 shows typical diagrams for punching tests, and Fig. 11 shows typical diagrams for shearing tests of zinc plate. In Fig. 11 are also shown diagrams of shearing tests of steel plate.

The results of the punching tests are summarized in Table 7 and the shearing tests in Table 8. The variation of the extreme values for ultimate strength of individual specimens from the average values reported in Tables 7 and 8 was, in general, not greater than 10 per cent. The variation in the amount of energy required was somewhat greater. As one of the principal items of information desired was a comparison between zinc and steel as to maximum stress developed and amount of energy required in punching and shearing, punching and shearing tests were made on mild steel plates and the results are summarized in Tables 9 and 10.

Fig. 12 shows the appearance at several stages of the punching process of the "wad" of zinc as it is being pushed out ahead

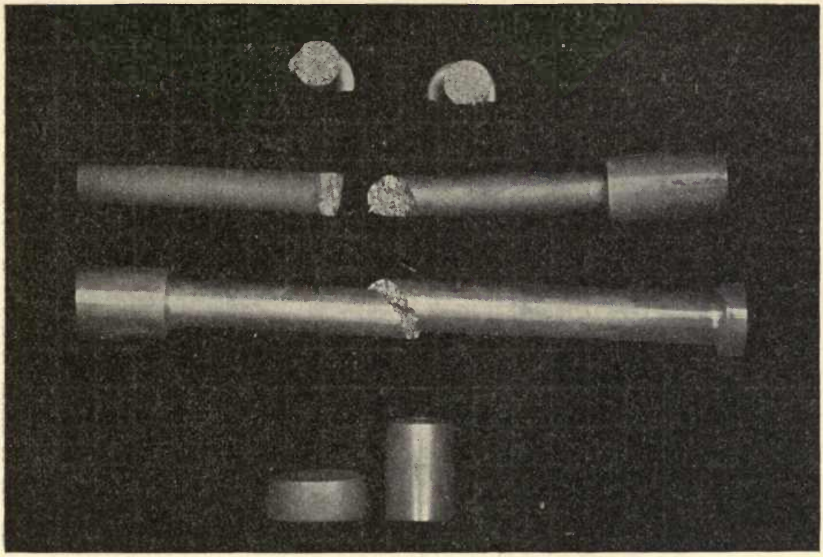

FIG. 8. SPECIMENS OF CAST ZINC AFTER TESTING.

of the punching tool. Fig. 12 also shows a shearing specimen which is about to fail. The distortion of the tool marks, originally straight, shows in a general way the distortion of the fibers of the specimen.

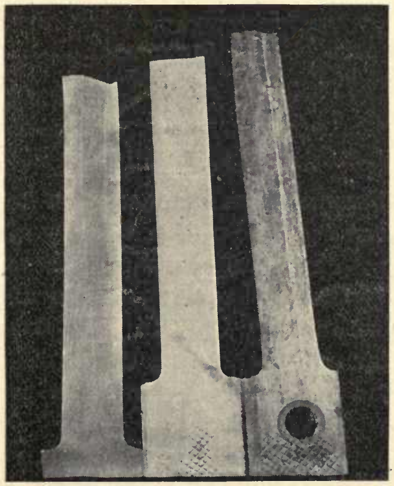

FIG. 9. SPECIMEN OF ROLLED ZINC AFTER TESTING IN TENSION.

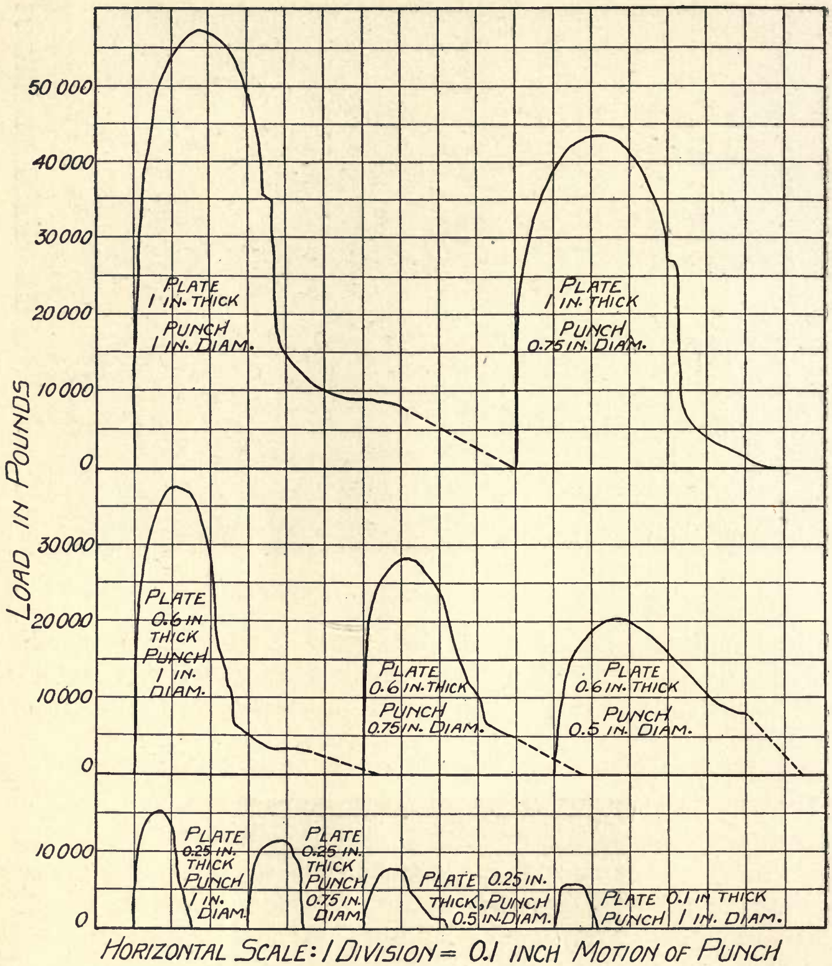


FIG. 10. PUNCHING TEST DIAGRAMS FOR ROLLED ZINC.

9. *Miscellaneous Tests.*—Torsion tests were made on six test pieces of cast zinc. The results of these tests are summarized in Table 11, and a typical stress-deformation diagram for torsion of cast zinc is shown in Fig. 13. In Fig. 8 are shown torsion test specimens after rupture. Attention is called to the character of the fracture, and its similarity in form to that of cast iron under torsion.

Compression tests were made on four short cylinders of cast zinc. The results of these tests are given in Table 12, and a typical stress-compression diagram for cast zinc is shown in Fig.

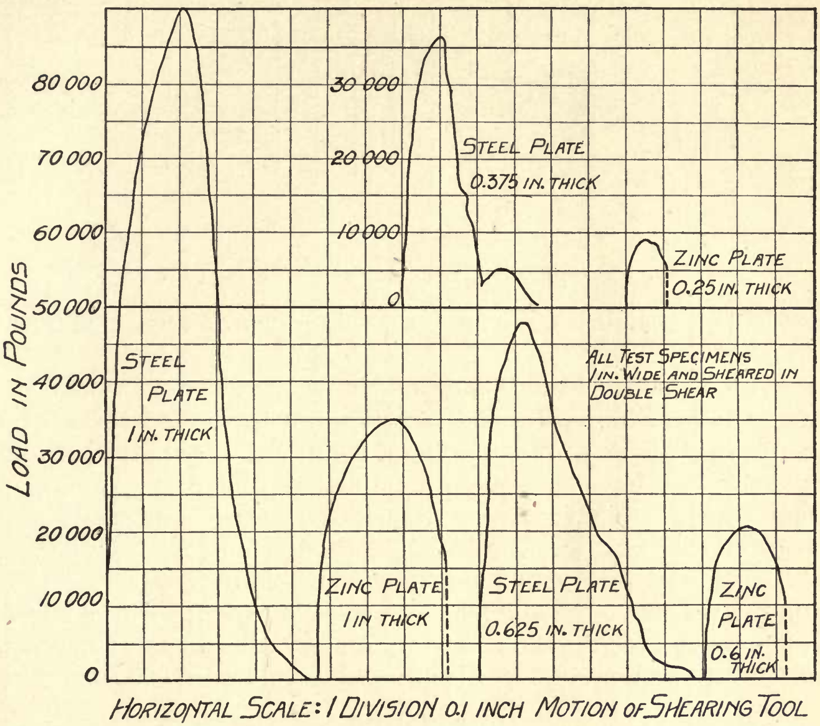


FIG. 11. SHEARING TEST DIAGRAMS FOR ROLLED ZINC AND FOR STEEL.

14. Fig. 14 also shows a stress-compression diagram for zinc under steadily increasing repetitive loading. Both in the repetitive loading test in compression and in tension (see Fig. 7) there was an appreciable loss of energy during the release and the reapplication of a load. This loss of energy, "mechanical hysteresis" as

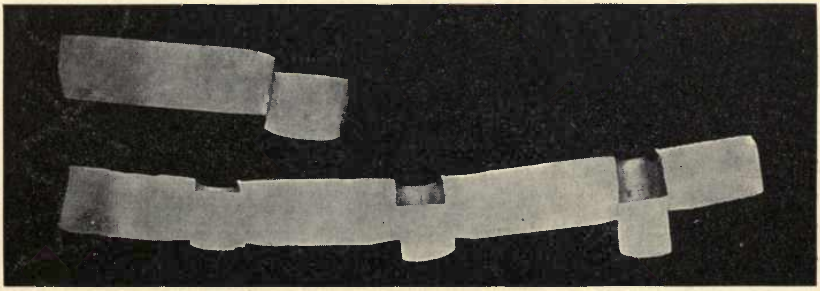

FIG. 12. PUNCHING AND SHEARING TEST SPECIMENS AFTER TESTING.

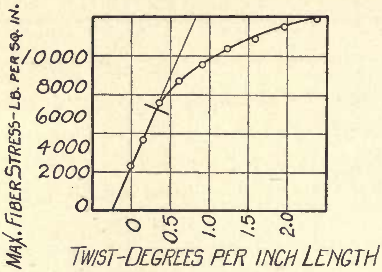


FIG. 13. TORSION TEST DIAGRAM FOR CAST ZINC.

it is called, is shown by loops in the diagrams of tests under repetitive load.

The behavior of cast zinc under compression is worthy of note. Judged by fractures in tension and in torsion tests, cast zinc is a brittle material, and under compression a shattering failure might be expected—such a failure as cast iron exhibits in compression. What actually happened to the compression test pieces of cast zinc was a gradual flattening out, such as occurs with soft steel. No maximum load could be determined. Cast zinc is evidently a plastic but not a ductile metal. Fig. 8 shows a cylinder of cast zinc before testing, and beside it another originally of the same size, after compression under 100 000 lb.

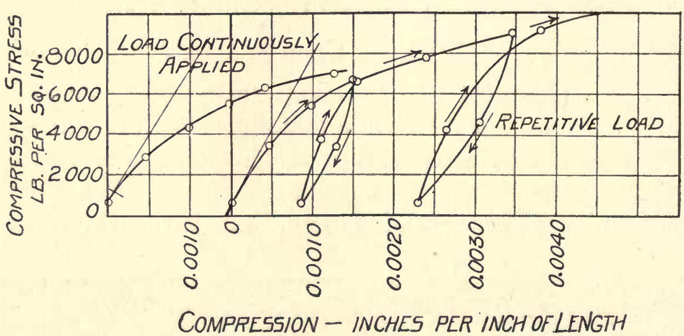


FIG. 14. COMPRESSION TEST DIAGRAMS FOR CAST ZINC.

Cold bending tests were made on specimens from all rolled plates except those 1 in. thick and those 0.6 in. thick. One test was made on specimens from a plate 0.6 in. thick. From each plate tested one specimen was bent in a plane parallel to the direction of rolling and one specimen bent in a plane perpendicular to the direction of rolling. Table 8 shows the results of the cold bending tests.

TABLE 7.

PUNCHING TESTS OF ZINC.

The values given are the average results for the number of specimens noted in the second column.

| Nominal Thickness of Plate in. | Number of Specimens Tested | Diameter of Punch in. | Speed of Punching in. per min. | Ultimate Shearing Stress Developed lb. per sq. in. | Energy Required to Punch in lb. per sq. in. per in. thickness |
|---|---|---|---|---|---|
| 1.00 | 9 | 0.75 | 0.10 | 18 750 | 7 260 |
| 1.00 | 9 | 1.00 | 0.10 | 19 060 | 6 650 |
| 0.60 | 6 | 0.50 | 0.10 | 19 740 | 10 590 |
| 0.60 | 6 | 0.75 | 0.10 | 19 350 | 8 630 |
| 0.60 | 6 | 1.00 | 0.10 | 18 990 | 6 400 |
| 0.25 | 6 | 0.50 | 0.10 | 20 000 | 10 550 |
| 0.25 | 6 | 0.75 | 0.10 | 19 700 | 8 740 |
| 0.25 | 6 | 1.00 | 0.10 | 19 390 | 8 030 |
| 0.25 | 6 | 1.00 | 0.50 | 19 400 | 8 350 |
| 0.25 | 6 | 1.00 | 1.60 | 20 850 | 8 380 |
| 0.10 | 6 | 1.00 | 0.10 | 18 230 | 5 650 |
| | | | | Av. 19 400 | 8 110 |
| 0.018* | 9 | 1.00 | 0.10 | 12 930 | —— |
| 0.018* | 6 | 1.00 | 0.10 | 13 380† | —— |
| 0.018* | 9 | 1.00 | 0.10 | 10 880 | —— |

* In the very thin plates, shearing took place unevenly around the circumference of the punching tool.

† Zinc bought in the local market.

TABLE 8.

SHEARING TESTS OF ZINC.

The values given are the average results for the number of specimens noted in the second column.

| Nominal Thickness of Plate in. | Number of Specimens Tested | Speed of Shearing Tool in. per min. | Ultimate Shearing Stress Developed lb. per sq. in. | Energy Required to Shear in. lb per sq. in. per in. thickness | Shearing with Grain or across Grain |
|---|---|---|---|---|---|
| 1.00 | 6 | 0.10 | 16 700 | 4 850 | Across grain |
| 1.00 | 3 | 0.10 | 16 580 | 4 510 | With grain |
| 1.00 | 6 | 0.50 | 17 140 | 4 130 | Across grain |
| 1.00 | 6 | 1.60 | 17 770 | 4 330 | Across grain |
| 0.60 | 6 | 0.10 | 16 580 | 5 100 | Across grain |
| 0.60 | 3 | 0.10 | 17 380 | 4 620 | With grain |
| 0.60 | 6 | 0.50 | 15 480 | 4 640 | Across grain |
| 0.60 | 6 | 1.60 | 18 100 | 4 410 | Across grain |
| 0.25 | 6 | 0.10 | 18 860 | 6 690 | Across grain |
| 0.25 | 3 | 0.10 | 18 170 | 4 620 | With grain |
| 0.25 | 6 | 0.50 | 15 480 | 4 640 | Across grain |
| 0.25 | 6 | 1.60 | 17 040 | 5 730 | Across grain |
| | | | Av. 17 100 | 4 850 | |

## III. Results and Conclusions.

10. *Tensile Strength of Zinc.*—An examination of the results of tension tests shows that zinc, either cast or rolled, is imperfectly elastic under very low stresses. The results of Meyer's tests are in agreement with the results of the Illinois tests as regards this general conclusion, though in the Illinois tests permanent set was detected at lower stresses than in Meyer's tests. Whether the elastic limit be defined as the lowest stress under which a material is given a permanent set, or as the lowest stress at which Hooke's law (proportionality of stress to deformation) is found to be inexact, the elastic limit of zinc is very low and very poorly defined. It is doubtful if the elastic limit as determined either by Meyer or in the Illinois tests has any special physical significance. Though Meyer reported a yield point of zinc in the tables of results of his tests, in the accompanying discussion he stated that the yield point was poorly defined. In the Illinois tests no well-defined yield point could be detected, and none was reported.

The ultimate tensile strength of cast zinc depends on the temperature of pouring, and other factors, and varies between wide limits. Thin plates of rolled zinc are relatively stronger under tension than thick plates. From the results of the Illinois tests for plates under 0.05 in. thick, 24 000 lb. per sq. in. would seem to be about the value to be used for the ultimate tensile strength of rolled zinc. For plates over 0.05 in. thick, 21 000 lb. per sq. in. would seem a reasonable value to use. Meyer's tests and those of the Matthiessen and Hegeler Zinc Company show slightly higher values. Rolled zinc is somewhat stronger in tension across the grain than in tension with the grain. A higher tensile strength of rolled zinc was obtained by increasing the rapidity of application of load. Rapidity of testing may, in part, account for the fact that higher values of tensile strength were found by Meyer and by Matthiessen and Hegeler than were found at Illinois. Neither of the first two reports the speed of testing. The speed used in the Illinois tests was lower than is sometimes used in commercial testing.

From the results of the various tension tests of zinc herein quoted, it would seem that the modulus of elasticity of zinc is about 11 500 000 lb. per sq. in.

11. *Shearing Strength of Rolled Zinc.*—The values of shearing strength of rolled zinc reported in this bulletin were determined with the purpose of throwing some light on the problem of what

TABLE 9.

PUNCHING TESTS OF STEEL PLATE.

For purposes of comparison with punching tests of zinc plates.

The values given are the average results for the number of specimens noted in the second column.

| Nominal Thickness of Plate in. | Number of Specimens Tested | Diameter of Punch in. | Speed of Punching in. per min. | Ultimate Shearing Stress Developed lb. per sq. in. | Energy Required to Punch in. lb. per sq. in. per in. thickness |
|---|---|---|---|---|---|
| 0.375 | 2 | 0.75 | 0.10 | 50 000 | 30 350 |
| 0.375 | 2 | 1.00 | 0.10 | 50 080 | 19 880 |
| | | | | Av. 50 040 | 25 200 |

TABLE 10.

SHEARING TESTS OF STEEL PLATE.

For purposes of comparison with shearing tests of zinc plates.

The values given are the average results for the number of specimens noted in the second column.

| Nominal Thickness of Plate in. | Number of Specimens Tested | Speed of Shearing Tool in. per min. | Ultimate Shearing Stress Developed lb. per sq. in. | Energy Required to Shear in. lb. per sq. in. per in. thickness | Shearing with Grain or across Grain |
|---|---|---|---|---|---|
| 1.000 | 2 | 0.10 | 44 700 | 11 580 | Across grain |
| 0.625 | 2 | 0.10 | 37 200 | 17 750 | Across grain |
| 0.375 | 3 | 0.10 | 46 970 | 18 850 | Across grain |
| 0.375 | 3 | 0.50 | 43 000 | 16 740 | Across grain |
| 0.375 | 2 | 1.60 | 44 500 | 19 630 | Across grain |
| | | | Av. 43 270 | 16 910 | |

TABLE 11.

TORSION TESTS OF CAST ZINC.

| | |
|---|---|
| Number of specimens tested.. | 6 |
| Maximum fiber stress at limit of proportionality of stress to angle of twist.... | 5 450 lb. per sq. in. |
| Computed maximum fiber stress at rupture.......... | 15 260 lb. per sq in. |
| Modulus of elasticity in shear (Torsion)................ | 4 570 000 lb. per sq. in. |

TABLE 12.

COMPRESSION TESTS OF CAST ZINC.

| | |
|---|---|
| Number of specimens tested.. | 4 |
| Fiber stress at limit of proportionality of stress to compression .................. | 1 620 lb. per sq in. |
| Modulus of elasticity.......... | 6 900 000 lb. per sq. in. |

sizes of punches and shears should be used in working with zinc plates. Two factors which are important in their influence on the design of punches and shears are the maximum force to be exerted during the process of punching or shearing and the energy required to complete the punching or shearing action. The maximum force to be exerted determines the strength of frame, ram, gearing, and other parts of the punch or shear; the energy required determines, in large measure, the weight of the flywheel, size of belt, and power required for power-driven punches and shears, or the power and amount of water or air required for hydraulic or pneumatic punches or shears. The maximum force to be exerted during the punching or shearing action is in general proportional to the area actually sheared under the action of punching or shearing tool; the mean force during the action is approximately proportional to the maximum force and consequently to the area under the action of the punching or shearing tool. (This may be seen from the general similarity of shape of the punching and shearing diagrams for different thicknesses of plate; see Fig. 10 and 11). The energy required to punch or shear any plate will then be approximately proportional to the area to be sheared (by punching or shearing tool) multiplied by the distance traveled by the tool during the punching or shearing action, i. e., by the thickness of the plate. The significant features of the punching or shearing tests of rolled zinc were, then, the maximum shearing stress developed measured in pounds per square inch, and the energy required for punching or shearing measured in inch-pounds per square inch of surface sheared per inch thickness. An examination of the results of the punching and shearing tests of zinc plate shows an average value of shearing stress developed of 19 400 lb. per sq. in. for the punching tests, and of 17 100 lb. per sq. in for the shearing tests. The average value of the energy required was 8 110 in. lb. per sq. in. per in. thickness for the punching tests, and 4 850 in. lb. per sq. in. per in. thickness for the shearing tests. Evidently the frictional resistance of the metal pushed out (the "wad") is greater in punching than in shearing, as is shown by the slightly greater stress developed, and by the markedly greater energy required.

An examination of the results of the punching tests shows that the larger the punch for any given thickness of plate the less the unit-energy required to punch the plate. In both punching and shearing tests, the maximum stress developed was slightly increased under increased speed of punching or shearing tool.

TABLE 13.

COLD BENDING TESTS OF ROLLED ZINC.

| Nominal Thickness of Plate in. | Specimen Bent with Grain or across Grain | Action under Cold Bending |
|---|---|---|
| 0.006 | Across Grain | Bent double and hammered flat without cracking. |
| 0.006 | With Grain | Bent double and hammered flat without cracking. |
| 0.018 | Across Grain | Bent double and hammered flat without cracking. |
| 0.018 | With Grain | Bent double and hammered flat without cracking. |
| 0.018* | Across Grain | Bent double and hammered flat without cracking. |
| 0.018* | With Grain | Bent double and hammered flat without cracking. |
| 0.100 | Across Grain | Two specimens bent double and hammered flat without cracking; one specimen cracked when hammered flat. |
| 0.100 | With Grain | All specimens bent double and hammered flat without cracking. |
| 0.250 | Across Grain | Specimens cracked when bent through 90–120 degrees. |
| 0.250 | With Grain | One specimen bent double and hammered flat without cracking; two specimens cracked after bending through 180 degrees. |
| 0.600 | Across Grain | One specimen tested, broke short off when bent through about 30 degrees. |
| 0.600 | With Grain | One specimen tested, cracked after bending through 180 degrees. |

* Zinc bought in local market.

Both punching and shearing tests were made with flat-faced tools, the object being to bring stress as uniformly as possible on all parts of the area under shear. By the use of beveled punching and shearing tools, the maximum force resisting shear would have been reduced.

An examination of the results of the punching and shearing tests of mild steel plate tested for purposes of comparison with rolled zinc shows the following average values: Shearing stress developed, 50 040 lb. per sq. in. for the punching tests, 43 270 lb. per sq. in. for the shearing tests. Energy required 25 200 in. lb. per sq. in. per in. thickness for the punching tests, and 16 910 in. lb. per sq. in. per in. thickness for the shearing tests*. In punching or shearing zinc plates, about 40 per cent as high a stress is developed as is developed in punching or shearing mild steel plates of the same size, and about 30 per cent as much energy is required.

*Other punching and shearing tests of mild steel give results not widely differing from these. See article by H. V. Loss in the American Engineer and Railroad Journal for March 1893 and results in Kent's Mechanical Engineers' Pocket Book.

12. *Ductility and Plasticity of Zinc.*—For the comparison of the ductility of different metals there is, unfortunately, no well-defined quantitative standard. In the series of tests described in this bulletin the elongation and the reduction of area after rupture in tension and the results of cold bending tests were all used to throw light on the ductility of the zinc tested. From the results of the tests, it is evident that zinc is much less ductile than wrought-iron or mild steel, and that it is less ductile across the grain than with the grain. For zinc plate which is to be stamped or bent into shape (for example in the making of zinc elements for dry batteries), a severe cold-bending test would seem to be of considerable value in determining the acceptability of a shipment of zinc plate.

The researches of Martens and of Meyer on the effect of heat treatment of zinc on its strength and ductility would indicate the desirability of measuring and of controlling the temperature in the rolling process and show the danger of rolling at too high a temperature. While the ductility of zinc is low as compared with that of steel, from the low and poorly defined elastic limit, from the loss of energy in "mechanical hysteresis" and from the behavior of compression test pieces it is evident that the zinc possesses a relatively high degree of plasticity.

13. *Summary.*—The following summary is given:

1. Zinc either rolled or cast has no well-defined yield point and its elastic limit is very low. Zinc possesses a relatively high degree of plasticity.

2. The ultimate tensile strength of thin rolled zinc plate (not more than 0.05 in. thick) is about 24 000 lb. per sq. in.

3. The modulus of elasticity of zinc in tension is about 11 500 000 lb. per sq. in.

4. The stress per square inch of area sheared developed in punching or shearing rolled zinc plates is about 40 per cent of the stress developed in punching or shearing mild steel plates.

5. The energy per square inch of area sheared per inch thickness of plate required to punch or shear rolled zinc plates is about 30 per cent of the energy required to punch or shear mild steel plates.

6. The ductility of rolled zinc is much less than that of mild steel, and the ductility of zinc plate with the grain is greater than the ductility across the grain.

## ANNOUNCEMENT CONCERNING A MODIFICATION IN THE RULES GOVERNING THE DISTRIBUTION OF BULLETINS

The Board of Trustees of the University of Illinois voted, December 3, 1910, that a price should be affixed to certain University publications, among them being the Bulletin of the Engineering Experiment Station.

This action, so far as it concerns the bulletins of the Engineering Experiment Station, has for its purpose a threefold object:

(1) To provide a greater degree of control in the distribution of bulletins.

(2) To make possible the establishment and maintenance of a trade circulation through the regular publishing houses.

(3) To regulate the distribution of the reserve or "out-of-print" supply.

IT IS NOT INTENDED THAT THIS ACTION SHALL OPERATE IN ANY WAY TO ABRIDGE THE PRIVILEGES OF THOSE WHO HAVE HITHERTO RECEIVED THE BULLETINS OF THE STATION GRATUITOUSLY, OR TO PREVENT REASONABLE EXTENSIONS OF THE EXISTING MAILING LISTS.

Practice under the new procedure will be as follows:

(1) All bulletins, hereafter issued, will have a price printed upon the cover, together with the name of the London sales agent.

(2) EACH BULLETIN, HOWEVER, WILL STILL BE SUBJECT TO A FREE INITIAL DISTRIBUTION, AS HERETOFORE, ON THE BASIS OF EXISTING MAILING LISTS.

It will also be placed on sale with authorized agencies, both in this country and abroad.

(3) THERE WILL BE A LIMITED NUMBER OF COPIES AVAILABLE FOR FREE DISTRIBUTION, UPON REQUEST, AFTER THE INITIAL DISTRIBUTION.

(4) As the supply of each bulletin approaches exhaustion, it will be placed upon a reserve or "out-of-print" list. THE EFFECT OF THIS ACTION WILL BE TO WITHDRAW SUCH BULLETINS FROM FREE DISTRIBUTION. Bulletins withdrawn from free distribution will be available to any applicant upon payment of the assigned price.

(5) A discount from the published price will be allowed to news agents regularly handling the bulletins.

W. F. M. GOSS
Director.

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### ALL BULLETINS, THE TITLES OF WHICH ARE NOT STARRED, WILL BE SENT FREE UPON APPLICATION.

**Bulletin No. 1.* Tests of Reinforced Concrete Beams, by Arthur N. Talbot. 1904 *None available.*

**Circular No. 1.* High-Speed Tool Steels, by L. P. Breckenridge. 1905. *None available*

**Bulletin No. 2.* Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905. *None available.*

**Circular No. 2.* Drainage of Earth Roads, by Ira O. Baker. 1906. *None available.*

**Circular No. 3.* Fuel Tests with Illinois Coal. (Compiled from tests made by the Technologic Branch of the U. S. G. S., at the St. Louis, Mo., Fuel Testing Plant, 1904-1907,) by L. P. Breckenridge and Paul Diserens. 1909. *Thirty cents.*

**Bulletin No. 3.* The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906. *None available.*

**Bulletin No. 4.* Tests of Reinforced Concrete Beams, Series of 1905, by Arthur N. Talbot. 1906. *Forty-five cents.*

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**Bulletin No. 9.* An Extension of the Dewey Decimal System of Classification Applied to the Engineering Industries, by L. P. Breckenridge and G. A. Goodenough. 1906. *None available.*

**Bulletin No. 10.* Tests of Concrete and Reinforced Concrete Columns, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

**Bulletin No. 11.* The Effect of Scale on the Transmission of Heat through Locomotive Boiler Tubes, by Edward C. Schmidt and John M. Snodgrass. 1907. *Fifteen cents.*

**Bulletin No. 12.* Tests of Reinforced Concrete T-beams, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

**Bulletin No. 13.* An Extension of the Dewey Decimal System of Classification Applied to Architecture and Building, by N. Clifford Ricker. 1907. *Fifty cents.*

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**Bulletin No. 18.* The Strength of Chain Links, by G. A. Goodenough and L. E. Moore. 1908. *Forty cents.*

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**Bulletin No. 20.* Tests of Concrete and Reinforced Concrete Columns, Series of 1907, by Arthur N. Talbot. 1908. *None available.*

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*Bulletin No. 26.* High Steam-Pressures in Locomotive Service. A Review of a Report to the Carnegie Institution of Washington, by W. F. M. Goss. 1908. *Twenty-five cents.*

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*Out of print; price attached.

*Bulletin No. 27.* Tests of Brick Columns and Terra Cotta Block Columns, by Arthur N. Talbot and Duff A. Abrams. 1909. *Thirty cents.*

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*Bulletin No. 43.* Freight Train Resistance, by Edward C. Schmidt. 1910. *Eighty cents.*

*Bulletin No. 44.* An Investigation of Built-up Columns under Load, by Arthur N. Talbot and Herbert F. Moore. 1911. *Thirty-five cents.*

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*Bulletin No. 46.* The Spontaneous Combustion of Coal, by S. W. Parr and F. W. Kressmann. 1911. *Forty-five cents.*

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*Bulletin No. 50.* Tests of a Suction Gas Producer, by C. M. Garland and A. P. Kratz. 1911. *Fifty cents.*

*Bulletin No. 51.* Street Lighting, by J. M. Bryant and H. G. Hake. 1911. *Thirty-five cents.*

*Bulletin No. 52.* An Investigation of the Strength of Rolled Zinc, by Herbert F. Moore. 1911. *Fifteen cents.*

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* Out of print; price attached.